Impact on Gaza aquifer from recharge with partially treated wastewater

Sami M. Hamdan, Abdelmajid Nassar and Uwe Troeger

ABSTRACT

The Gaza Strip suffers from high pressure imposed on its water resources. There is a deficit of about 50 mm^3 every year, which has led to a declination of groundwater level and deterioration of groundwater quality. New water resources are sought to fulfil the water deficit; among them is the artificial recharge of treated wastewater to groundwater. The impact of recharging partially treated wastewater in Gaza was tested through a pilot project implemented east of the existing wastewater treatment plant. The daily application of about 10,000 m^3 of effluent to infiltration basins had an effect on the aquifer, which was monitored through the surrounding operating water wells over five years from 2000 until 2005. Although the monitored wells are operated for irrigation by farmers, impacts were clearly noticed. Groundwater levels improved and an increase in some areas of 0.6 m within three years was observed. The nitrate ion concentration also decreased in the groundwater due to nitrification processes. However, chloride ion, which indicates salinity, increased because the effluent has high chloride concentration. Boron levels increased in some areas to 0.5 mg/l, which could affect sensitive crops grown in the area.

Key words | effluent, groundwater, pollution, recharge, reuse, water quality

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INTRODUCTION

The increasing water demand and limited water resources in Palestine in general, and in the Gaza Strip in particular, have led to the depletion of the water systems quantitatively and qualitatively. The aquifer in the coastal region, i.e., Gaza Strip, suffers from high pressure imposed by supplying domestic and agricultural needs. The overall water use is 164 mm^3 per year, where the overall supply is only 122 mm^3 per year (PWA 2007). This means that there is a deficit of about 42 mm^3 every year. The deficit has led to a continuous declination of groundwater level and deterioration of groundwater quality.

The policy of water resources management is to use non-conventional water resources such as seawater desalination and artificial recharge of groundwater from storm water and treated wastewater. The agricultural demand is almost constant since the agricultural areas are limited or even decreasing. However, the domestic demand increases due to the rapid growth of the population. This increases the amount of wastewater produced and the treated effluent becomes a significant resource of water that could improve the water balance in the region. The reuse of this effluent could be accomplished in two ways: either by direct irrigation to farms and/or through artificial recharge to groundwater, which is then pumped to irrigate farms with reclaimed wastewater.

Water demand is continuously increasing due to economic development and population increase, due to natural growth and returnees, while the water resources are constant or even decreasing due to urban development (CAMP 2000). The Gaza Strip is classified as a semi-arid region and suffers from water scarcity. The renewable amount of water that replenishes the groundwater system is much less than the demanded amount, and this has resulted in deterioration of the groundwater system in both quantitative and qualitative aspects (PWA 2000a). The Palestinian Water Authority seeks other resources to fill

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the water gap between the supply and the demand and to attain sustainable water resources management. There are large quantities of wastewater estimated at 40 mm^3 every year (CMWU 2007) that are produced by the municipal sewerage systems and the treated effluents are disposed to the sea or flooded without good treatment or control to the surrounding areas and underground aquifer. Biological oxygen demand (BOD) is reduced from 440 to 140 mg/l, while chemical oxygen demand (COD) is reduced from 900 to 300 mg/l through the poor treatment at Gaza plant (CMWU 2007). For direct reuse of wastewater, more treatment is needed to reach the Palestinian standards for direct reuse in agriculture.

Some projects adopted by the Palestinian Water Authority were started with the reuse of treated wastewater obtained from the Gaza Wastewater Treatment Plant (GWWTP), which is the case study in this paper. An amount of about 10,000 m^3 is diverted to infiltration basins of an area of four hectares every day (PWA 2004). The crops grown in this area are mostly citrus and olives. The water wells that recover the reclaimed wastewater mixed with native groundwater were monitored for groundwater level fluctuations and chemical analyses of their pumped water.

The quality of the native groundwater in the zone of the pilot project showed high values of nitrate ranging from 39 to 177 mg/l with an average of 118 mg/l as shown in Table 1. The high value of nitrate concentration comes from intensive application of chemical fertilizers in the agricultural activities in the area. The salinity of the native groundwater is expressed in the form of chloride ion ranging from 217 to 607 mg/l so this part of the aquifer is relatively good compared to other regions in the Gaza Strip. Any application of treated wastewater to the aquifer through artificial recharge should be recovered from well-designed recovery wells in addition to continuous monitoring of the groundwater to predict any pollution that may occur. At the same time, the project is at least two kilometres away from public water supply wells that are used for drinking purposes.

Table 1 | Quality of native groundwater in the zone of the pilot project

Well No.	Sampling	EC (μS/cm)	Cl^- (mg/l)	NO_3^- (mg/l)
R/135	25 July 1999	1,465	239	162
R/141	31 March 1999	2,568	607	177
R/255	12 July 2000	1,412	217	144
R/112	30 October 2000	1,680	322	67
R/254	30 October 2000	2,038	392	39
Average		1,833	355	118

According to the Palestinian strategy, a minimal amount of wastewater will be used for agricultural purposes such as soil flushing and irrigation of high-value crops. It is planned that wastewater reuse will be 34 mm^3 in 2010, increasing to 63 mm^3 in 2020 (PWA 2000a). Part of the reused amount will be diverted directly to the farms, and the rest will be recharged artificially through infiltration basins and other schemes to undergo soil aquifer treatment (SAT) processes that purify the effluent. From previous studies on the biological impact on groundwater, it was determined that SAT was efficient in removing faecal coliforms and faecal streptococci, and removed 85% of total BOD and COD applied in the effluent (Abushbak & Al Banna 2005).

Conventional water resources

The Gaza Strip depends mainly on conventional water resources coming from natural infiltration of rainfall that feeds the Pleistocene sandstone aquifer. Average annual rainfall fluctuates from 200 mm in south Gaza to 400 mm in the north, giving a bulk amount of water of about 115 mm^3, from which only 42 mm^3 infiltrate to the aquifer and the rest either evaporates or floods and runs off to the sea. The total supply was 120 mm^3/year, and the total demand was 165 mm^3, which led to a total deficit of about 45 mm^3 (CAMP 2000) and this deficit increases with time. The population in the Gaza Strip was estimated at 1,443,814 in 2006 leading to a total domestic demand of 79 mm^3 and the total agricultural consumption of 85.5, giving a total water demand in the Gaza Strip of 165 mm^3 (PWA 2007). Therefore, there is an annual deficit in the water budget of about 50 mm^3.

Non-conventional water resources

Due to the increasing demand and fixed supply of the groundwater system in Gaza, it became urgent to allocate new non-conventional water resources in order to fill the gap in the water budget. The potential resources that could be used are seawater desalination, wastewater reuse and storm water harvesting. According to a Coastal Aquifer Management Program (CAMP) study in 2000, it was planned that the amounts of treated wastewater that will be reused in 2020 will reach about 60 mm^3 every year and another 55 mm^3 will come from seawater desalination.

Some wastewater reuse projects are seen in the PWA area, in the north, middle and south of the Gaza Strip. In North Gaza the effluent is already flooded to the surrounding are of the wastewater treatment plant without control. According to the Sogreah (2001) feasibility study, it was found that the most feasible solution of this flooding effluent is to use controlled infiltration basins if compared with other solutions such as pumping the effluent to the sea or to the future treatment plant in the east of Northern governorate. The Swedish financed study proposed an area of 3,600 ha to be irrigated with treated wastewater (World Bank 2004a). In Rafah City, in the south of the Gaza Strip, the existing wastewater treatment plant is efficient and needs upgrading. However 10 ha close to the plant are proposed if the effluent is improved and reached WHO guidelines for irrigation (World Bank 2004a). The local people showed acceptance to use reclaimed wastewater. About 60% of the local people in the Gaza Strip are highly willing to use treated reclaimed wastewater for irrigation use, and about 22% are highly willing to use the reclaimed wastewater for domestic uses such as toilet flushing, washing, etc. (World Bank 2004b).

METHODOLOGY

A review of the strategic plans of the wastewater reuse were carried out and interpreted. Part of the treated effluent (10,000 m^3) from the existing wastewater treatment plant in Gaza was diverted to three spread infiltration basins with a total base area of 3.7 hectares (ha) distributed to three ponds: pond 1 with an area of 1.1 ha, pond 2 of 1.3 ha and pond 3 of 1.3 ha (CAMP 2001a) as shown in Figure 1. The three ponds were undergoing one day wetting and two days drying periods. The impact on groundwater levels and chemical quality was evaluated based on previous monitoring of the surrounding groundwater wells in different directions, where the water samples were analysed in the laboratory of the Palestinian Ministry of Agriculture according to the American Standard Method Manual. The samples were analysed for boron, Cl, NO_3, detergents and other ions, of which Cl, NO_3 and boron are interpreted in this paper. Due to different political, financial and social constraints, it was not possible to drill monitoring wells beside the infiltration basins. However, the existing operating wells were sufficient at this stage, and water samples were taken from them.

The infiltration areas located east of the current Gaza Waste Water Treatment Plant (GWWTP) is considered here. This project started in 2000 with the help of USAID through the CAMP project. The treatment plant receives about 40,000 m^3 every day and all of the effluent was pumped to the sea before the construction of the infiltration facilities. In 2000, about 10,000 m^3 were pumped to the infiltration basins.

RESULTS AND DISCUSSION

The infiltration basins are set on an area with groundwater of medium quality between fresh and brackish, where chloride concentration in the area fluctuates between 250 and 500 mg/l and nitrate concentration fluctuates between 50 and 200 mg/l (PWA 2008). The quality of the treated effluent was monitored in the period from January 2002 to November 2004. This showed a range of chloride level between 400 and 600 mg/l, which is slightly greater than that in native groundwater. However, the nitrate level in the treated effluent ranged between 20 and 30 mg/l in the same period, and this will dilute the nitrate concentration in the native groundwater. The Palestinian standards of effluent recharge are set at 600 for chloride and 20 mg/l for nitrate (KfW 2005). The reclaimed wastewater was planned to be pumped from six recovery wells, and the effect of the infiltration process was to be monitored in ten surrounding wells (CAMP 2001b). Due to local political conditions, the monitoring wells were not constructed and the monitoring itself was done in the existing operating wells owned by the farmers.

Impact of infiltration on groundwater levels

The ground elevation at the zone of the pilot projects ranges from 30 to 40 m above sea level, where two clayey

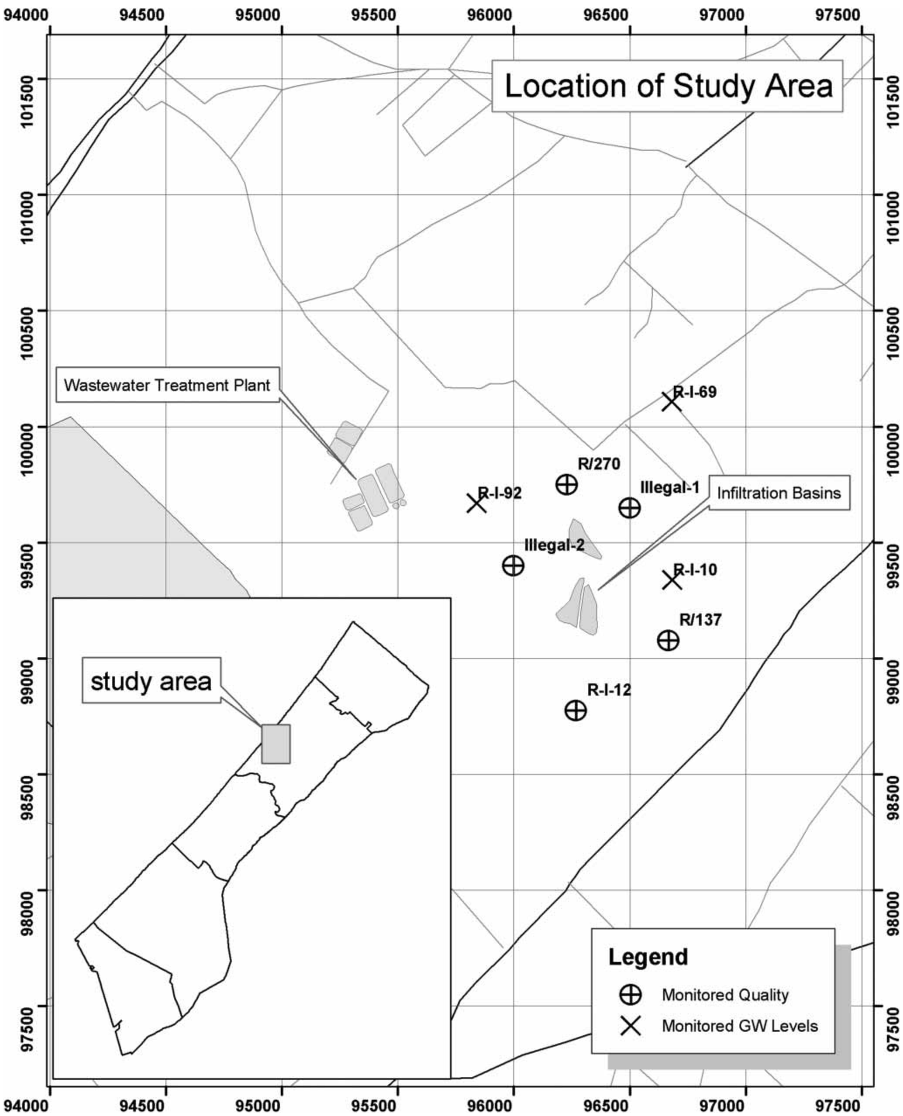

Figure 1 | Location map of infiltration area and monitored wells.

sand layers alternating with sand and sandstone are found at depths of 20 to 30 m below the ground surface (PWA 2001). For recovery well (R/137) ground surface is 40 m and the total depth of the well is 47.62 m and groundwater elevation of 4.0 m a.m.s.l. (PWA 2000b). According to the regional monitoring of groundwater levels, groundwater flows from the east to the sea in the west. However, due to the water mound created by the artificial recharge of wastewater in the study zone, the direction of groundwater flow becomes radial outward from the infiltration basins.

The area is surrounded by irrigation wells and monitoring the water levels in these gives an approximate indication of the influence of infiltration on the groundwater levels. Three operating water wells were monitored after the application of treated wastewater infiltration in the allocated basins. In well R-I-10, which is about 500 m east from the infiltration basin, there was an increase in water level of about 0.6 m by the end of 2003, almost constant during the whole period of infiltration since 2000 (Figure 2). The other monitored wells, which are R-I-69 (1,500 m north-east from the basins) and R-I-92 (1,000 m north-west

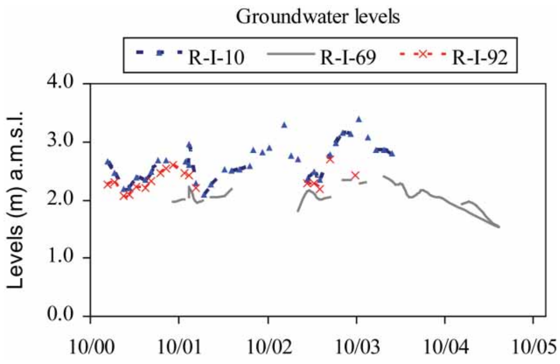

Figure 2 | Groundwater levels in wells around infiltration basins.

from the basins), showed slight decreases in the groundwater levels. No doubt that there was input to the groundwater system from the application of infiltration but the continuous abstraction through irrigation wells in the area hides the positive influence on the groundwater levels.

Impact of infiltration on groundwater quality

Five operating water wells in addition to the effluent recharge basins were selected to study the influence of effluent infiltration on the native groundwater quality. There was a clear increase in the chloride ion concentration in the monitored wells since the concentration level in the effluent is more than that of the native groundwater (Figure 3). The chloride concentrations in the study area range from 200 to 700 mg/l, depending on the layer from which water is pumped. Most of the water supplied through the municipal pipe networks has a chloride level of over 500 mg/l. Consequently, the sewage has naturally almost the same chloride level as this is not affected by the treatment processes in the wastewater treatment plant.

From the chemical analyses of effluent, the chloride level was found to be in the range from 400 to 600 mg/l. According to (Icekson-Tal & Blanc 1998), chloride in applied effluent in the Dan Region was 289 mg/l and after SAT processes it was observed to be 266 mg/l. In Gaza, effluent infiltration has negatively affected the salinity (chloride level) in the native groundwater in the area since chloride came from the high concentration effluent and without removal through SAT. This is considered as a threat to artificial recharge using effluent.

Figure 4 shows that the nitrate level in the effluent is much less than the nitrate level in all of the surrounding monitored wells. A slight decrease in nitrate concentrations was observed in all monitored wells, especially in well R-137, which is the closest to the infiltration basins (about 300 m east of the infiltration basins). In this case the infiltration has improved the quality of the groundwater in terms of nitrate level, from which most of the water wells in the Gaza Strip suffer. In the Dan Region case, the same conclusion was reached where the total nitrogen in the applied effluent decreased from 10.8 to 3.19 mg/l through SAT processes, i.e., removal was 70.5% (Icekson-Tal & Blanc 1998).

From an agricultural aspect, even though boron is an essential micronutrient for plants it may cause toxicity to sensitive crops when concentrations in irrigation water exceed 0.5 mg/l (FAO 2000). Boron concentrations monitored in the infiltrated effluent for 2002 until 2005 fluctuate from about 0.4 to 1.0 mg/l. This has negatively affected water quality in the neighbouring wells, most

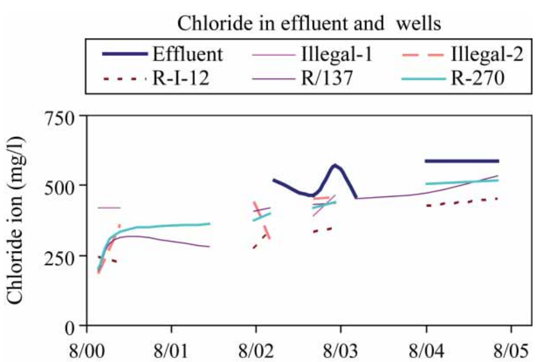

Figure 3 | Chloride levels in effluent and surrounding wells.

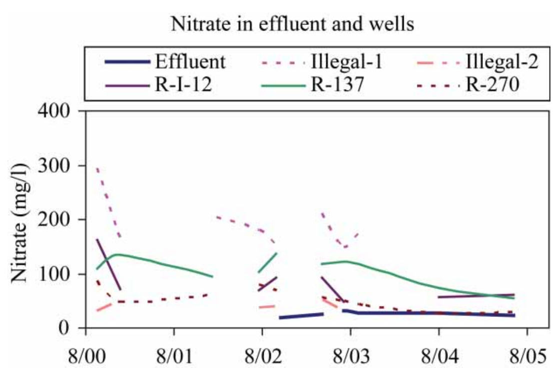

Figure 4 | Nitrate levels in effluent and surrounding wells.

obviously in the well closest to the basins. The boron concentration was 0.234 mg/l in January 2002 and increased to 0.61 mg/l in June 2005 (Figure 5). In other wells, there was a clear increase in boron concentrations. In well R-270, boron increased from 0.232 mg/l in January 2002 to 0.482 mg/l in July 2003 and then decreased to 0.24 mg/l in June 2005. In well R-I-12, boron increased from 0.29 mg/l in January 2001 to 0.635 mg/l in April 2003 and decreased to 0.2 mg/l in June 2005. The latter well results indicate clear influence on native groundwater on boron as SAT is not efficient in removing boron from the infiltrated water. The analyses of more chemical parameters carried out in June 2005 of the effluent and water from surrounding water wells are shown in Table 2 according to PWA (2008).

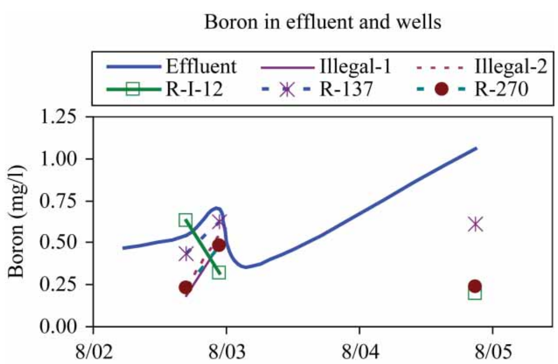

Figure 5 | Boron levels in effluent and surrounding wells.

In a similar area in the Dan Region, boron was removed during percolation in the early stage of the project. However, after several months, boron increased gradually in the recovery wells until it reached the same concentration as the effluent (Idelovitch & Michail 1985; Icekson-Tal & Blanc 1998), and SAT efficiency decreased. Boron removal was minimal (1.8%) as its concentration was 0.54 mg/l in the applied effluent and was observed to be 0.54 mg/l in the groundwater (Icekson-Tal & Blanc 1998).

Locally, in the Gaza Strip, boron compounds are reduced under high pH depending on the process; pH precipitation is likely indicated and advisable. There are some ion exchange compounds that can achieve the desired level, again subject to objectives. For example, a zeolite process with caustic soda may raise the pH to 9.5 or 10. This may precipitate elemental boron by 60%.

Socioeconomic impact

From the economic point of view, a cost estimation was carried out by SWECO (2003) for the infiltration system on infiltration of treated wastewater of the North Gaza governorate. The expected wastewater production for 2012 is 35,600 m^3 every day and it needs 8 ha for infiltration basins. The initial investment cost was 4.58 M USD including infiltration basins and construction of recovery wells

Table 2 | Water quality of effluent and water wells surrounding the infiltration basins

			Water from recovery wells							
Parameter	**Unit**	**Effluent water**	**R-270**	**R-137**	**R-I-54**	**R-I-69**	**R-I-92**	**R-139**	**R-I-10**	**R-I-12**
pH		8.0	7.6	7.2	7.0	7.3	7.8	8.6	7.4	7.4
TDS	mg/l	2,173	1,720	1,860	1,773	1,085	937	664	1,360	1,560
NO_3^{-1}	mg/l	23	30	55	483	265	63	33	101	60
Cl^{-1}	mg/l	587	516	535	376	197	269	120	384	454
B	mg/l	1.1	0.2	0.6	0.2	0.0	0.1	0.2	0.2	0.2
Deterg.	mg/l	0.9	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.1
Ca^{2+}	mg/l	109	96	104	125	119	55	29	86	80
Mg^{2+}	mg/l	57	79	79	90	68	51	17	73	101
K^+	mg/l	37.5	4.5	8.0	2.3	2.5	3.0	2.0	3.8	6.0
Na^+	mg/l	406	311	350	298	109	163	157	227	250
TOC	mg/l	11.9	2.0	2.7	1.8	0.2	0.4	0.4	2.4	1.9
BOD	mg/l	45.0	5.0	7.0	2.2	4.6	3.2	3.5	1.3	2.3
COD	mg/l	135	10.0	11.0	10.0	0.0	10.0	5.0	10.0	0.0

and pipes, while the operational cost was 0.14 M USD per year. Assuming that the investment system will operate for 20 years to infiltrate 35,600 m^3 per day i.e., 12.3 mm^3 per year, this will give an initial investment cost of 0.019 USD for each cubic metre infiltrated. The operational and maintenance costs for each cubic metre will be 0.018 USD. The total cost for each cubic metre is 0.037 USD for every cubic meter, which has been also reached by (Nassar *et al.* 2009), where 0.04 USD per cubic metre was estimated for operational costs. This cost is acceptable for Gaza, which is considered as a scarce water region. At the same time, the farmers pay 0.5 USD for each cubic metre pumped for irrigating their crops (PWA 2006). According to the survey conducted in a later study (PWA 2006), the farmers showed interest and willingness to pay 0.14 USD for each cubic meter of reclaimed effluent, where 68% of farmers in north Gaza and 91% of farmers in south Gaza are willing to use reclaimed wastewater either as direct reuse or from recovery wells (Nassar *et al.* 2009).

To convince the users, the reclaimed wastewater should be treated through the SAT in addition to preventing technical problems occurring in the distribution system and establishing an appropriate institutional framework to operate the system. The quality levels of reclaimed wastewater for irrigation should be managed well in terms of suspended solids to avoid blockage of the irrigation system, nutrients to adjust fertilization, salinity to estimate soil leaching requirement and control of pathogens to protect public health. The infiltration system itself needs to be properly assessed environmentally to prevent hazards to the neighbouring residents. From the other side, the public should be aware of the advantages of the new water sources, together with economic incentives to reclaim wastewater with a lower price than well water.

The current wastewater production is 32.7 mm^3 per year for the partial coverage of wastewater networks and it is estimated at 51.6 mm^3 if full coverage of wastewater services is achieved, as shown in Table 3. With a population growth rate of 3.5%, the total wastewater production will increase to 80 mm^3 per year by 2020. According to the National Water Plan (PWA 2000a), this will provide an input to water resources of about 60 mm^3 per annum by 2020.

Table 3 | Wastewater production in Gaza governorates[a]

Governorate	Population (capita)	Coverage percent (%)	Wastewater production (m^3/day)	Production with full coverage (m^3/day)
North Area	298,125	68.51	16,341	23,851
Gaza	546,959	79	48,243	61,067
Middle area	223,679	64	11,420	17,843
Khanyounis	299,918	20.60	4,942	23,988
Rafah	183,649	59.79	8,784	14,691
			89,730	141,440

Total production = 32.7 million m^3/year and 51.6 million m^3/year for full coverage, and based on average per capita of 80 l/day.
[a]CMWU (2007).

CONCLUSION AND RECOMMENDATIONS

Like other scarce water countries in the region, there is an urgent need to look for new non-conventional water resources such as reuse of reclaimed wastewater. The policy of the Palestinian Water Authority is to reduce the amount of fresh water to be used for irrigation (83 mm^3/year) by replacement with reclaimed wastewater after ensuring sufficient treatment. This new water resource will play an important role together with other resources, e.g., seawater desalination and harvesting of storm water, in the sustainability of the water resources in the Gaza Strip. Potentially, about 63 mm^3 of treated wastewater (22% of total water demand) could be available for reuse by 2020 (CAMP 2000).

Although the quantity of effluent infiltrated to the aquifer is currently small compared to the strategic planned amounts, it has had a slight positive impact on improving the continuous declined water table, which rose 0.6 m. A positive decrease in the nitrate concentrations in the recipient aquifer was observed. However, the trend of boron concentrations is a concern as concentrations in the aquifer exceed the WHO recommended value of 0.5 mg/l.

Chloride concentration in the public water supply is high in most of the areas in the Gaza Strip, and consequently the chloride level will be high in wastewater and treated effluent since this is not removed by wastewater treatment. Consequently, recharged effluent had negative impact on the chloride concentrations in the aquifer and is a challenge for artificial recharge of groundwater under the local conditions. It is recommended to reduce the salinity of the public water supply to reduce the level of chloride in the treated wastewater so that effluent becomes suitable for infiltration.

Previous studies have shown that infiltration of effluent through soil layers removed microorganisms and a large part of organic matter. In areas with a high boron level in effluent, it is recommended to use conventional treatment technologies (metal hydroxide precipitation) to reduce the boron level. Reverse osmosis (RO) is another recommended technology for boron reduction.

From the economic aspect, reuse through infiltration of effluent is feasible. The total cost of infiltrated effluent is 0.035 USD per cubic metre. However, more efforts are still needed on the socioeconomic and technical aspects. On the technical dimension, the applied effluent should be treated well in the treatment plant so that its constituents do not exceed the standards adopted by the Palestinian Water Authority based on WHO standards, in addition to the well-control on the management of infiltration spread basins. On the socioeconomic dimension, the public should be prepared to accept the idea of replacing their well water with distributed reclaimed wastewater for irrigation, and they should be economically encouraged through the pricing of the received water.

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REFERENCES

Abushbak, Th. H. & Al Banna, M. 2005 Soil aquifer treatment system using secondary treated wastewater: Sheikh Ejlin plant, Gaza. In *Proceedings of Conference on Water, Values and Rights*. Ramalla, Palestine 20095, p. 492.

CAMP 2000 *Coastal Aquifer Management Program. Volume I. Integrated Aquifer Management Program, Task 3. Metcalf and Eddy in association with Camp Dresser & McKee and Khatib & Alami*, Gaza, May 2000, pp. 3.1–3.15.

CAMP 2001a *Coastal Aquifer Management Program. Feasibility Study and Conceptual Design for Gaza Wastewater Treatment Plant, Task 23. Metcalf and Eddy in association with Camp Dresser & McKee and Khatib & Alami*, Gaza, March 2001, pp. 8.9–8.10.

CAMP 2001b *Coastal Aquifer Management Program, Task 25. Metcalf and Eddy in association with Camp Dresser & McKee and Khatib & Alami*, Gaza, September 2001, pp. 3.13–3.15.

CMWU 2007 *Databases of the Coastal Municipal Water Utility*. Gaza, 2007.

FAO 2000 *User Manual for Irrigation with Treated Wastewater*. Cairo, Egypt, p. 9.

Icekson-Tal, N. & Blanc, R. 1998 Wastewater treatment and groundwater recharge for reuse in agriculture. Dan Region Recharge Project, Shafdan. In *Proceeding of International Conference TISAR 98*. Rotterdam, 1998, p. 103.

Idelovitch, E. & Michail, M. 1985 Groundwater recharge for wastewater reuse in the Dan Region Project: summary of five-year experience, 1977–1981. In: *Artificial Recharge of Groundwater* (T. Asano, ed.). California State Water Resources Control Board and Department of Civil Engineering University of California. Butterworth Publishers. Boston. London. Sydney. Wellington. Durban. Toronto, pp. 502.

KfW 2005 *Sludge and Effluent Reuse Study for Gaza Central Area*. Concept Report, Volume I. Dorsch Consult, Gaza, July 2005, p. 3–2.

Nassar, A. R., Al-Najar, H. & Al-Dadah, J. 2009 Socio-economic aspect of wastewater reuse in the Gaza Strip. *J. Environ. Sci. Tech.* **2** (4), 170–178.

PWA 2000a *National Water Plan*. The Palestinian Water Authority, Gaza, December 2000, p. 5 (B-2-6).

PWA 2000b *Summary of Palestinian Hydrologic Data, Volume 2: Gaza*. Palestinian Water Authority, Data Bank Department, with technical and financial support USAID and USGS, p. 440.

PWA 2001 *Impact of Gaza Wastewater Treatment Plant Infiltration Basins on Groundwater Quality*. Water Resources and Planning Department, Hydrology Section, December 2001, p. 4.

PWA 2004 *Hydrogeological Impact Assessment of GWWTP Infiltration Basins on Local Groundwater*. Gaza, December 2004, p. 6.

PWA 2006 *Effluent Reuse Study for Khan Younis Governorate*. Finland Project-PWA, Gaza, July 2006, pp. 32, 54.

PWA 2007 *Agricultural and Municipal Water Demand in Gaza for the Year 2006*. Gaza, September 2007.

PWA 2008 Databases of the Palestinian Water Authority on groundwater quality (accessed 4 May 2008).

Sogreah 2001 *Beit Lahia Wastewater Project*. Interim Report. Gaza, July 2001.

SWECO 2003 *Northern Gaza WWTP Infiltration System*. Final Report. SWECO International AB, Stockholm, October 2003, pp. 71–72.

World Bank 2004a *West Bank and Gaza Wastewater Treatment and Reuse Policy Note. Volume 2: Preferred Reuse Options and Pilot Projects*. June 2004, pp. 13–17.

World Bank 2004b *West Bank and Gaza Wastewater Treatment and Reuse Policy Note. Volume 2: Accompanying Annexes to the Main Text, Annex E*. June 2004, pp. 30–40.

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